Course 42

Seeing in 3D

Bob Parslow and Geoff Wyvill

Most people, even among technical draftsmen, designers and computer graphics programmers, find it very difficult to visualize 3D shapes well enough to reason about them. We demonstrate the problem and take participants through a series of exercises whereby they can begin to acquire this important practical skill.

The Speakers

Geoff Wyvill

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Geoff Wyvill is well-known in SIGGRAPH circles having contributed technical presentations, artworks and animation to many conferences as well as presenting parts of the implicit surface courses in 1990, 1993 and 1996. He is a professor in the Department of Computer Science at the University of Otago and a director of *Animation Research Limited,* a production company that makes commercial animation and animation software and produces a weekly children's TV show. He has a BA in physics from Oxford University and MSc and PhD in computer science from Bradford (UK).

Over many years he has decried specialization and encouraged scientists into artistic pursuits and artists to learn science. He has published about sixty technical articles and papers and given numerous invited talks and courses. He serves on the editorial boards of *The Visual Computer, Computer Graphics Forum, Visualization and Computer Animation, The Journal of Shape Modeling,* and *Virtual Reality.*

Bob Parslow

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Bob Parslow was Senior Lecturer in the Computer Science Department at Brunel University, UK, where he ran the early international conferences on Computer Graphics, before setting up "on-line" with Richard Elliott Green.

He discovered "3-D Blindness" - the inability to visualize simple 3-D objects - which affects 96% of the population. He found a way to cure it which takes about a day. With Geoff Wyvill at the University of Otago he extended the theory to cover general problem solving and learning techniques. This 3-D Perception and Problem Solving are now part of the Computer Science Syllabus at the University of Otago. This research has led him into the psychology of perception of 3-D objects and its applications.

He is a Chartered Engineer and a Fellow of the British Computer Society (FBCS). He has served on the Council of the BCS and he is a member of their technical board. He was European representative on the Council the Association for Computer Machinery and, as an ACM Lecturer, gave seminars on this topic worldwide.

Introduction

Thinking in two dimensions comes easily. Our eyes present us with 2D images of the 3D world so we are already used to it. A well designed figure can explain, in a moment, a tricky idea in mechanics, mathematics or in art. Since we inhabit a three dimensional world, it is tempting to imagine that the even richer world of 3D illustration would work the same way. But most of us find it appallingly difficult to think in 3D at all. Why should that be?

In most of our daily lives, the problems we need to solve in 3D do not require logical thinking. Opening doors, avoiding obstacles and catching balls are good examples. We have learned to solve these problems by 'switching off' the logical process. As soon as we see a 3D problem, our subconscious mind switches off our logic for us. We will show you how to switch it on again.

The purpose of this course is to teach a practical skill. And this skill can only be acquired with practice. So these notes consist mostly of exercises and problems to test your increasing ability. The exercises are organized in four sections following the four sessions of the one-day course.

We have not given 'answers' to the problems. Reading someone else's answer is a short cut to *convincing yourself* you have understood. As your spatial reasoning ability increases, you will develop confidence in your own answers. Some answers will be discovered during the course.

Contents

The schedule is a guide only. The course is interactive. The exercises may take more or less time than we have estimated. Therefore, we do not guarantee that the activities will all happen in the order given or in the sessions stated. It is not really sensible to attend only part of this course.

The four sessions will, however, start and finish on time.

Session 1, 8.30 –10.00

1.1 The Hidden Man

Fig. 1

For most people the picture in Fig. 1 appears as a patchwork of black and white of no particular form. Look at the picture after reading *each line* of the following description.

- It is a picture of a man.
- It shows the head and shoulders of a man.
- He is lit from the right.
- The head is turned towards you.
- The top of the picture cuts across his brow.
- The face is in the middle of the top half of the picture.
- The man is bearded.
- The man has long hair.

At some point the picture suddenly becomes clear. Rarely, some people still cannot see the picture. They should try viewing the picture from a distance, half closing their eyes and squinting.

We recognize the picture which is presented on the retina by establishing points of similarity with our previously organized ‘personal database.’ In this context it is interesting to note that the picture is seen by some people as Jesus Christ, but others see it as widely different-looking bearded men: Che Guevara or Ringo Starr.

1.2 The SIGGRAPH Subway

Many cities have a subway or similar local rail system. The maps that describe them are usually laid out according to the logic of connection rather than follow the city's geography. To illustrate this, we have created the Simplified SIGGRAPH Subway. Some of you will find the station names familiar.

The Simplified SIGGRAPH Subway has six lines with stations listed below. Where a station appears in more than one line, there is an interchange, so I can travel from De Rose to Simms, changing from Red Line to Blue Line at Kajiya.

Red Line	Green Line	Brown Line
Coons	Lasseter	Kass
Whitted	Foley & van Dam	Nakamae
Salesin	Bresenham	Whitted
De Rose	Giloth	Rushmeier
Prusinkiewicz	Brown	Catmull
Blinn	Sedeberg	Fuchs
Kajiya	Cox	Smith
Perlin		Baum
Sedeberg		De Fanti
		Reeves
		Cox

Gray Line	Loop Line	Blue Line
Kawaguchi	Cohen	Hanrahan
Fuchs	Terzopoulos	Crow
Glassner	Glassner	Meier
Blinn	Greenberg	Simms
Bresenham	Baraff	Greenberg
Parke	Cunningham	Kajiya
Igarashi	Rogers	
Musgrave	Prusinkiewicz	

How do I go from:

Salesin to Cox?
Kawaguchi to Perlin?
Hanrahan to Lasseter?
Rogers to Parke?
Cunningham to Kass?
Baum to Perlin?

What are the best routes? Actually, it's quicker to walk from Rogers to Parke. The color map, Fig. 19 on page 29, enables you to solve the problem in 2D. It is, of course, much easier.

1.3 Identical cubes

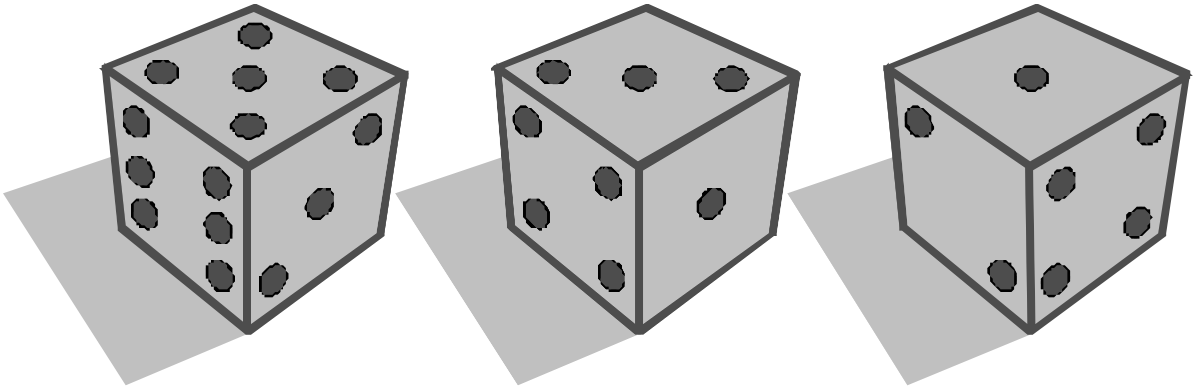


Fig. 2

Are the cubes portrayed in Fig 2. identical? Since we can see only three sides of each cube, we can never say “yes,” but there may be enough information for us to say “no.” So the answer is either “no” or “possibly.”

If you can rotate a cube in your imagination this question is easily answered. The people who can do it are usually astonished at the inability of the majority who cannot.

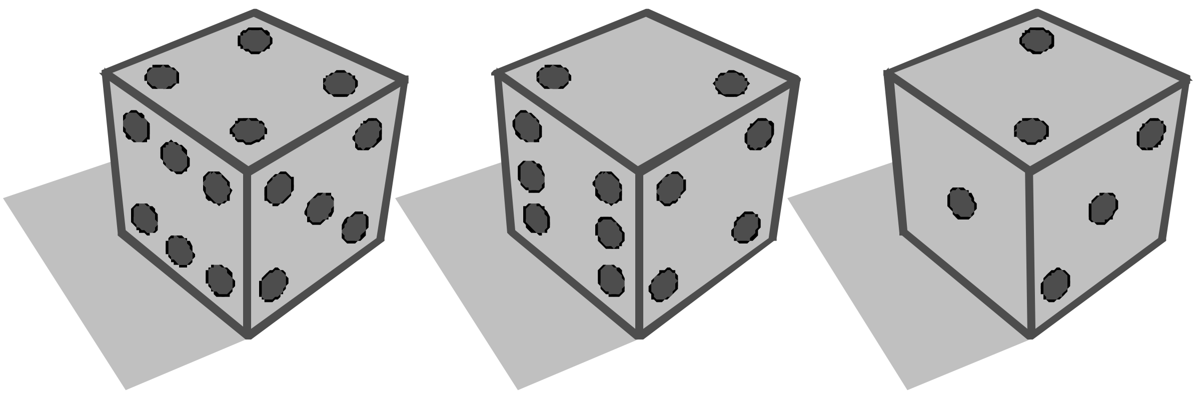


Fig. 3

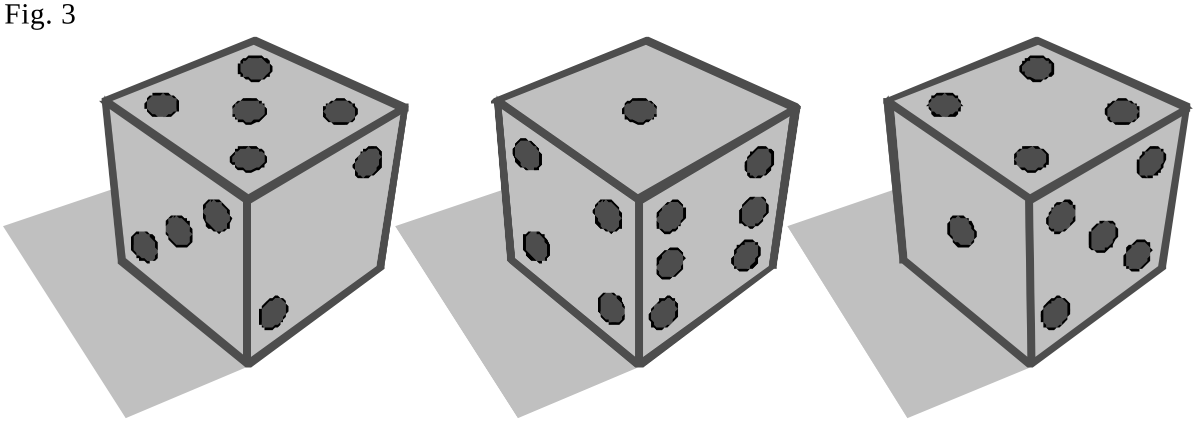


Fig. 4

Can you solve this for the figures on this page?

1.4 A cube on its corner

When we visualize we have to reconstruct an object in our minds, and the brain uses tricks to make it easier. Try the following. You will need pencil and a sheet of paper on the table in front of you.

Imagine a large cube in your hands. Concentrate on the cube. Hold opposite faces of the cube between your hands. Feel how hard it is. Tip it from side to side and feel the weight change.

What color is it? Did it have a color before you read the question?

When you are happy with the cube, balance it on one corner on the sheet of paper on the table. You can now move the upper hand to the top corner and release the other hand.

With your free hand, touch and name each of the other corners (ignore top and bottom) with letters A, B ...

- *Write down these letters.*

Imagine pushing the corner into the table until it makes a hole about an inch across.

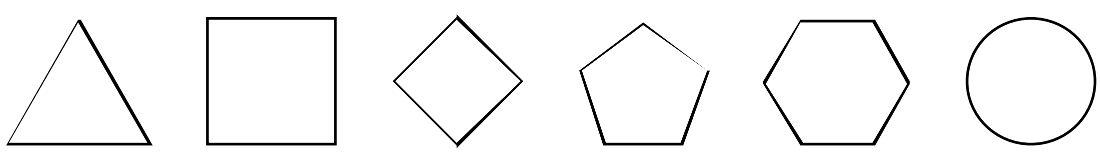
- *Pencil round the edge of the hole.*

What did you write?

A *AB* *ABC* *ABCD* *ABCDE* *ABCDEF*

Most people write *ABCD*. Is it right?

What shape was your hole?



A *B* *C* *D* *E* *F*

Something like 96% of the general population get C. Find a cube-like object and work out what it should be.

1.5 The mind as an expert system shell

Historically, spatial ability has been required for survival in fight/flight conditions so that in spatial learning the motor response is so closely linked to external stimuli that we can eventually react inside artificially measured ‘reaction time.’ As we practise, RNA in the neurons produce a protein which enables us to enhance our performance, improving some connections all over the brain and inhibiting others. In order to accomplish this fast response all efforts are concentrated into the response and all non-essential elements are disconnected. We respond ‘without thinking’. The mind has reorganized those sections (‘libraries’) of the brain that it needs and has closed the libraries that it has learnt are not needed. It has responded like an expert system shell. (see Visualization for 3-D Computer Graphics, Austrographics ’88)

When we need to calculate or reason about a spatial situation the libraries that deal with reasoning are closed and in order to open them we have to return to simple shapes: to visualize, calculate and reason about them. We build on the familiar and use what we already know. So the first rule of visualization is:

Be familiar.

It is extremely difficult to visualize tiny objects, so make sure that you enlarge the structure to improve visibility:

Make it big.

The third rule of visualization is an extension of the first two, by personal involvement. Try to imagine yourself close to, or even inside the object. If you can explore the shape by moving your hands or your body, you will understand the shape in a way that is very difficult by vision alone:

Be there.

1.6 Building shapes in layers.

Because we think easily in 2D, we can use the familiarity of 2D shapes to help us learn to visualize 3D shapes. In this exercise, we build imaginary shapes as piles of flat tiles arranged in layers.

Start with a square, about three feet on one side. This is your imaginary tile. It lies on a table in front of you. Hold it by the two nearest corners. Now imagine that the tile jumps up just three inches off the table, keeping flat. As it jumps it makes a click. Try saying “click” to reinforce the idea in your imagination.

Now suppose the tile drops back to the table, also saying “click.” Do this several times.

Next, we repeat the exercise, but imagine that at each ‘click’ the tile leaves a copy of itself behind. With each click, the tile rises three inches sitting at the top of a pile of tiles. After twelve clicks, the tile has risen three feet. What is the shape of the pile of tiles?

Now lets do it again but imagine that at each click the tile jumps up, leaves a copy and shrinks. It stays square but shrinks by three inches.

After twelve clicks what shape have you built?

Repeat, but make the tile shrink in one direction only so it shrinks to a line instead of a point.

One last time, let the tile shrink to a point but in the corner of the tile, not in the center.

The four shapes are sketched on the next page, Fig. 5. But please don’t look until you have created them for yourself. Can you work out the volume of each solid?

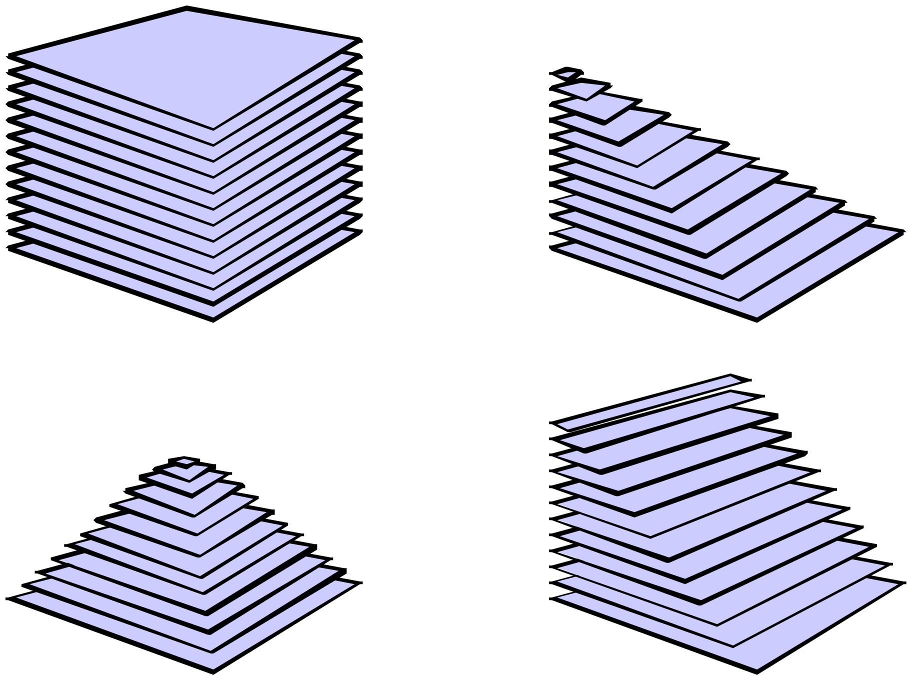


Fig. 5: Building shapes in layers from the imagination.

The two pyramids are each one third of the volume of the cube. Is it possible to build a cube from three pyramids?

1.7 More pyramids

Fig. 6 shows two pyramids. One is the familiar ‘Egyptian’ pyramid on a square base the other is built on a triangular base. Now suppose all the faces are equilateral triangles. All the edges are the same length. Put two square pyramids side by side on a table so that two base edges lie together. Can you fit the triangular pyramid into the gap between them. Sketch the shape you get. Are there any gaps?

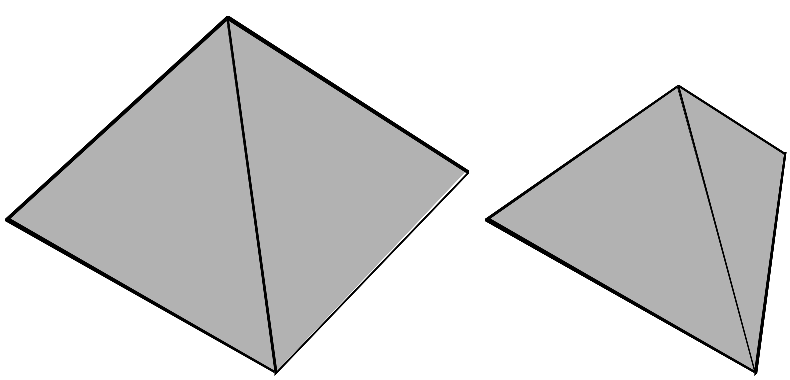


Fig. 6

Session 2, 10.15 – 12.00

2.1 The eye

We should be aware of some features of how the eye works. The retina contains receptors, which have differing features. These detect light and send signals to the brain which interprets the scene according to its ‘extant database.’ We see according to our experience. The cones detect color and respond fast and are concentrated mostly in the central area, the fovea. The rods detect in monochrome and respond more slowly.

Detecting movement

Put your hands together out in front of you and keep looking straight ahead. Very slowly pull your hands apart until you can no longer see them. Then wiggle your hands. You can see them! The receptors at the edge of the retina detect movement.

Fovea vision

Now we reverse the process. Pick up a small card with a letter on it or get a friend to write a letter on each thumb nail. You shouldn’t know in advance what the letters are. Move your hands from the spread out position slowly to the front, and stop as soon as you can distinguish the letters. You will notice that your hands are very close. You are within fovea vision range. Outside this area we have poor resolution.

3D perception

Consciously and subconsciously, we deduce the 3D structure of what we see from various depth cues in the scene. Examples are:

Occlusion: nearer objects hide further ones.
Perspective: distant objects appear smaller.
Shading: enables us to deduce relative distances from surface direction.
Reflections: reflection and object are equally distant from reflective surface.
Translucence: object lit from behind is nearer than light.
Color and haze: distant objects have less saturated color.
Motion parallax: Nearer objects move past the eye faster.
Binocular stereo vision: different views from two eyes give parallax.

But sometimes, we see conflicting cues and this gives rise to optical illusions.

2.2 Illusions

The Otago Corner

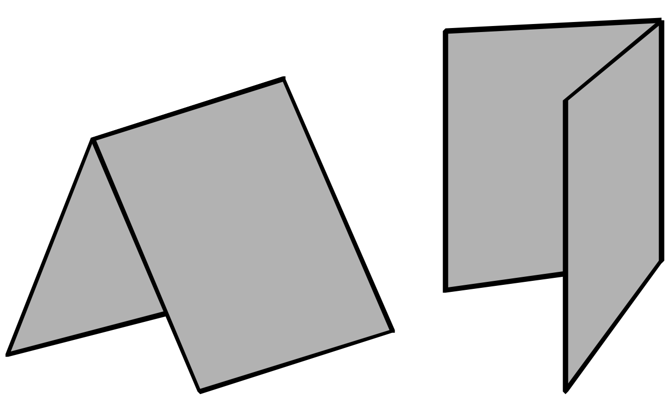
The Otago corner is made as a cut-out from Fig. 23 on page 32. Viewed through one eye it looks like a box. If you move your head slowly, the ‘cube’ seems to follow you. The shape of the corner and the markings on it have been designed to increase the illusion.

The Birthday Card

Take a piece of stiff card, bend it in half, and place it with the ridge uppermost (to look like a ridge tent) with the ridge running directly away from you. Close one eye and stare down into the entrance of the tent at an angle of about 60° to the horizontal. After a while - it can take several minutes - the card appears to stand up. It resembles an open book instead of a tent, Fig. 7. Success is worth the effort. With this illusion seemingly every depth cue is false.

Perspective:	The card actually looks off square.
Shadow:	Inexplicable with the illusory shape.
Lighting:	The card is apparently variably lit from inside.
Parallax:	The card appears to distort as you move.
Stereo:	With practice the effect can be obtained with both eyes.

If, instead of setting the card as a tent, the birthday card is set standing up and stared at with one eye closed until it looks like the tent, reverse illusions are possible, accentuated as the viewpoint is slowly changed. A new series of illusions can be obtained by folding the card into different shapes. Parts of the card then appear to move in opposite directions as the head is moved. The most sensational illusion is obtained by laying a ‘W’ folded card on top of the original ‘A’ folded card. The top card can then be made to appear to fly.



A B

Fig.7:

Viewed with one eye, the ridge shape, A, becomes a book, B.

Some people who are unable to accept the presented picture in this, and the next, experiment have to jerk their head away. How can the mind reject the picture that it itself presents, and cannot regain reality without using the motor sectors?

The spinning cube

Hang a black, wire frame cube from one corner against a light background, and spin the cube. If watched from about eight feet, the direction of spin suddenly seems to reverse. Moving towards the cube breaks the illusion and the cube appears to resume its correct direction of spin. However, if you close one eye and move slowly towards the cube you can keep the illusion. If you can get close enough to the cube, while it is still reverse rotating, the cube appears to distort in an extraordinary manner. A near face is apparently expanded and distanced, while a far face apparently shrinks and comes close. This dynamic flexing of the cube is the most powerful illusion I have ever witnessed, and some subjects become very disturbed.

An extension suggested by Prof. Richard Gregory involves setting a stick from the axis of the cube to extend outside the cube. The presence of the stick makes it more difficult to see a reversal of the cube, but eventually both the cube and the stick reverse. If you close one eye and slowly approach the cube, at a certain point the wider angle subtended by stick causes it to revert to the correct direction but the cube still rotates in the opposite direction, the stick and cube apparently passing through each other.

How can the mind accept such an impossible version of reality? These last two experiments show that the usual depth clues are not sufficient to produce a version of reality.

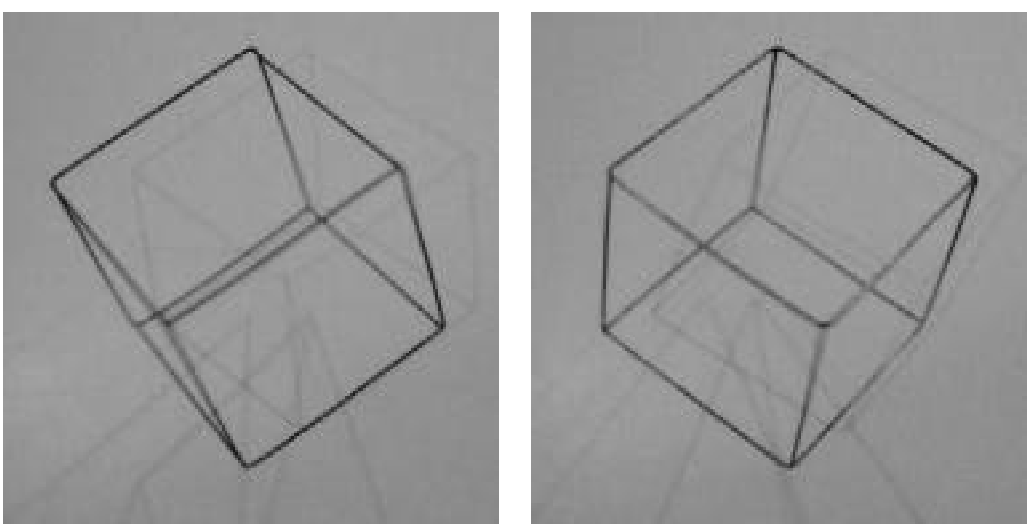


Fig. 8: Two views of a spinning cube. A movie of this is included with the CD version of these notes.

2.3 Lines in space

Suppose that we are to make a film “Joan of Arc”, about the French martyr, and we wish to provide some subliminal information, suggesting her saintliness and death, in the shot. Maybe we could show her against a scaffold, better still we could show two poles of a scaffold crossing behind her head. Evidently we could choose two poles tied at right angles in a vertical plane, but this would restrain the movement of the actor. Let us put two poles at an angle, but apart (so they don’t meet - ever): one at about 45° to the vertical, across the backdrop bottom left to top right; the other through the right foot of the backdrop and leaning at a slight angle out into the shot also up about 45°. Now, how is Joan restricted in her movement, if we want the poles to appear to cross behind her head?

Fig. 9: Can we move the camera so that the poles appear to cross behind St. Catherine’s head? (Sorry Joan. I just like Raphael’s St Catherine.)

To make the point clearer: Imagine the poles to be in the room where you are sitting. One across the wall facing you (top corner to the diagonally opposite floor corner), and the other from the corner directly under the first pole, out, to a point on the ceiling. Do they appear to cross? If you moved about in the room would they still appear to cross? Imagine that you are holding the camera and that you walk diagonally across the room keeping the poles crossing in the centre of the viewfinder. How would the camera angle change? Is there anywhere in the room where they don’t appear to cross? Can you specify where that is?

We have the two imaginary poles that don’t cross (though they appear to). We will add a third not to meet either of them - maybe a ceiling beam. Is it possible to position a fourth pole to touch the other three?

Answer quickly, then think about it carefully, so that you can produce a reason for your answer.

If you found one can you find another, a fifth pole to touch the first three?

If you found a fourth and fifth, do they meet?   Why?

Think again about where the two poles did not appear to cross. Evidently if you could not see them both, they would not appear to cross, and this would be true if you were 'between' them. Now we come to the difficult part. What does 'between them' mean? If the poles lay on a table we could say where 'between' them was, and if they were two walls we could say where it was, but they are two poles, not surfaces, and they don't lie in the same plane. Try moving about in this dead area 'between.'

We can avoid the problem by realizing that when we look at the lines we can think of the "line of sight" as a line (or another pole). Now the problem resolves into choosing a point, instead of your eye, and putting a pole from there to the two first poles. Evidently you can do this even 'between' them!! You still need to think about what 'between them' means.

These questions only seem difficult because they require you to reason about space. As soon as we encounter a 3D problem, we try to turn off the 'reasoning.'

2.4 An application in mathematics

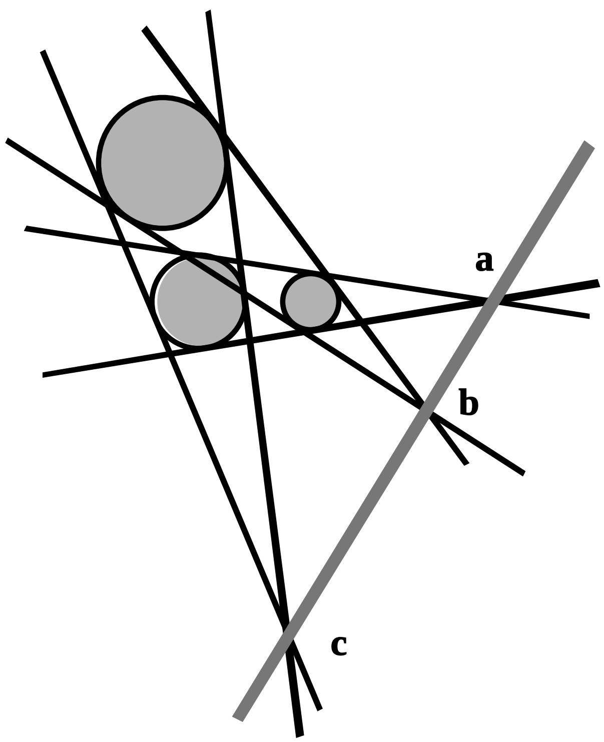


Fig. 10

Suppose we have three circles. They are all of different size. We can draw a pair of tangents to each pair of circles – the black lines in Fig. 10. The tangents in each pair meet at a, b and c. Can you prove that a, b and c lie on a straight line?

This is easily done if you move the problem into 3D. How?

2.5 More cubes

We have already presented the idea of a cube, balanced on its corner, being pushed into a surface. Visualize the shape of the hole as a cube is slowly pushed through a thin sheet of ice. We now know that the corner makes a triangular hole in the ice.

What happens as the cube is pushed slowly through the ice?

There are three edges meeting at that bottom corner. We can call the other ends of those edges the X, Y, and Z corners. There are also three edges attached to the top corner with corners at the other ends of them. Call them the A, B, and C. Does an A, B, or C corner or an X, Y, Z corner hit the ice first?

What is shape the hole in the ice at each stage as the cube descends?

Sinking the cube

We can illustrate the use of the three rules of visualization in solving this problem.
Make it Big and **Be There.** Imagine a six-foot cube suspended over the ice by one corner, and imagine that you are inside it. How have you placed your feet? Think of a corner of the floor of the room that you are in. In your imagination (or do it for real, if it helps), lie on your back on the floor and put your feet, one on each wall. If the whole room were to be tipped, you would be in the cube! Being over ice is not very familiar, but being over water on a float is. So **Be Familiar** and imagine that the cube is being lowered into water. We already knew that at first, the lines on each of the three faces, which meet at the bottom corner, form a triangle. As the cube is lowered into the water, the triangle gradually grows until the X, Y, and Z corners reach the water level.

What happens next?

Remember standing on a raft and how a corner sank as you moved towards it? Remember how the water rose to the corner and then, as the corner sank, how a line of water cut across the corner? So choose the corner of your cube opposite and imagine how the dry face at the corner (a square attached to the top) would sink into the water. The water cuts across the corner. So the point of the triangle becomes an extra edge. Similarly, at the other two corners. So we get three extra edges forming a hexagon. The new edges cut the corners of the still expanding edges. The new edges grow as the old edges shrink. So, eventually, all the edges are equal and we get a regular hexagon.

Go through the process of ‘seeing’ the cube and water until you ‘see’ the hexagon.

Cross sections of a cube

Imagine a cube lying horizontally on a table. We are going to take slices through the cube, but the cube is always complete. We don't remove any part.
Concentrate on the cube.

The first slice will be vertical through a diagonal of the top face. What is the shape of the cross section? Many people answer "Sq...rectangle" the strong tendency to have a square cut in a cube, until they realise that one side of the cross section is as long as the cube face diagonal.

Now concentrate on that rectangle. A diagonal of this rectangle is a 'body diagonal' of the cube. Now imagine another plane through this line, at right angles to the the first. How does *this* plane cut the whole cube? This seems very difficult but, let us examine the position carefully:

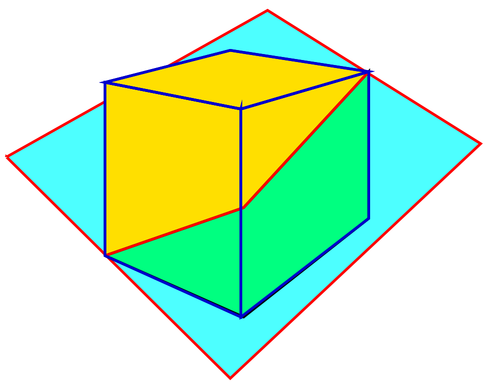


Fig. 11: A hint

The rectangle that we found had corners at the opposite corners of the cube. As we rotate the plane about the body diagonal, two of those corners, top right and bottom left in Fig. 11, are going to stay fixed. The position at the other two corners is symmetric, so concentrate on what happens at the other top corner of the rectangle as the plane begins to rotate. The intersection begins to move from the corner along a top edge and then down a vertical edge. When we reach the point half-way along this vertical edge, the plane has turned through a right angle. Fig. 11 shows the result.

You probably didn't follow that description at all. Read it slowly. You will not follow unless you really go through the process and visualize each stage.

We can make it easier with a few more figures but that doesn't help you to do it yourself. Fig. 11 is a progress check. For some perfectly capable people, there is an hour's work on this page. Others will see it immediately.

2.6 Curious engineering drawings

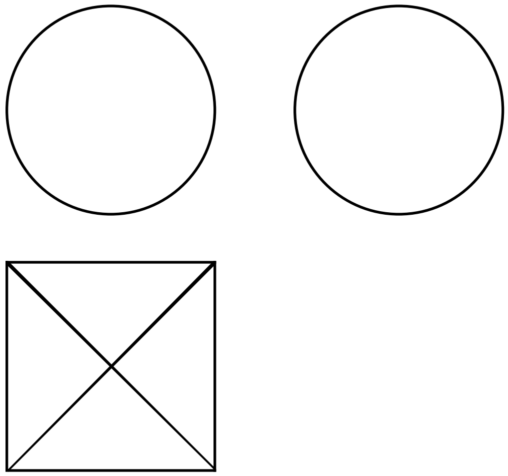


Fig. 12

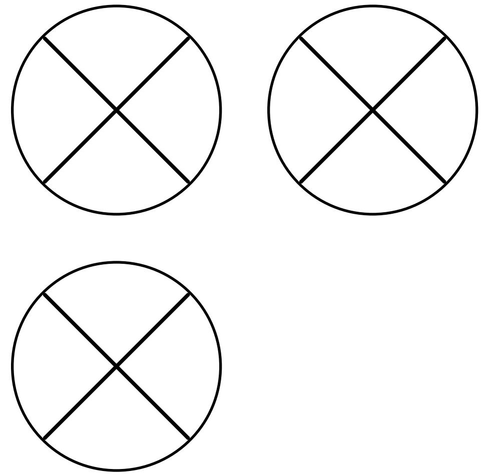


Fig. 13

Fig. 12 and Fig. 13 are engineering style drawings of two solid shapes. The drawings follow standard conventions. There are no hidden lines left out and none of the lines shown is concealed. Each figure shows three views of a solid from three directions at right angles. Think of these views as ‘front’, ‘side’ and ‘plan.’

Your task is to sketch these two solids to show you have understood the figures. This is not easy and even experienced engineers cannot always do it.

Session 3, 1.30 – 3.00

3.1 Solids of intersection

The intersection of two shapes is the part of space that lies inside both of them. This is easy to see in 2D. Fig. 14 shows you an intersection of a square and a circle.

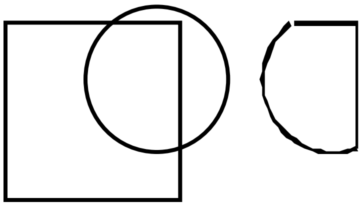


Fig. 14

In 3D, it is much harder to see. We are going to find the intersection of two cubes. Imagine a cube pushed into ice as in Section 2.5. Now imagine that the surface of the ice is a mirror. What is the intersection of the cube and its reflection?

Next, we construct the intersection of two cylinders. This is very hard to see from the outside. Imagine that you are walking *inside* a circular tunnel and you come to a place where two tunnels cross. Find the edges where the walls of the tunnel meet. What shape are they? These edges also describe the shape we are looking for.

3.2 Origami

Origami is the Japanese art of paper folding. In this exercise, we learn to fold a crane. The Japanese crane (tsuru) is a symbol of health and long life. Instructions for making the crane can be found in any standard origami book, but you have to learn to read the diagrams. This is quite a sophisticated notation.

In the course, we show you by live demonstration. The color plate, Fig. 22 on page 31, shows the process stage by stage.

What do we learn from paper folding? We learn about the behaviour of paper. We also practise logical thinking while doing something physical. This exercise expands your visualization without your realizing it.

3.3 Tensegrity

You are asked to build the structure shown in Fig. 15. All you need is six wooden rods with slots in their ends and a piece of string, Fig. 16.

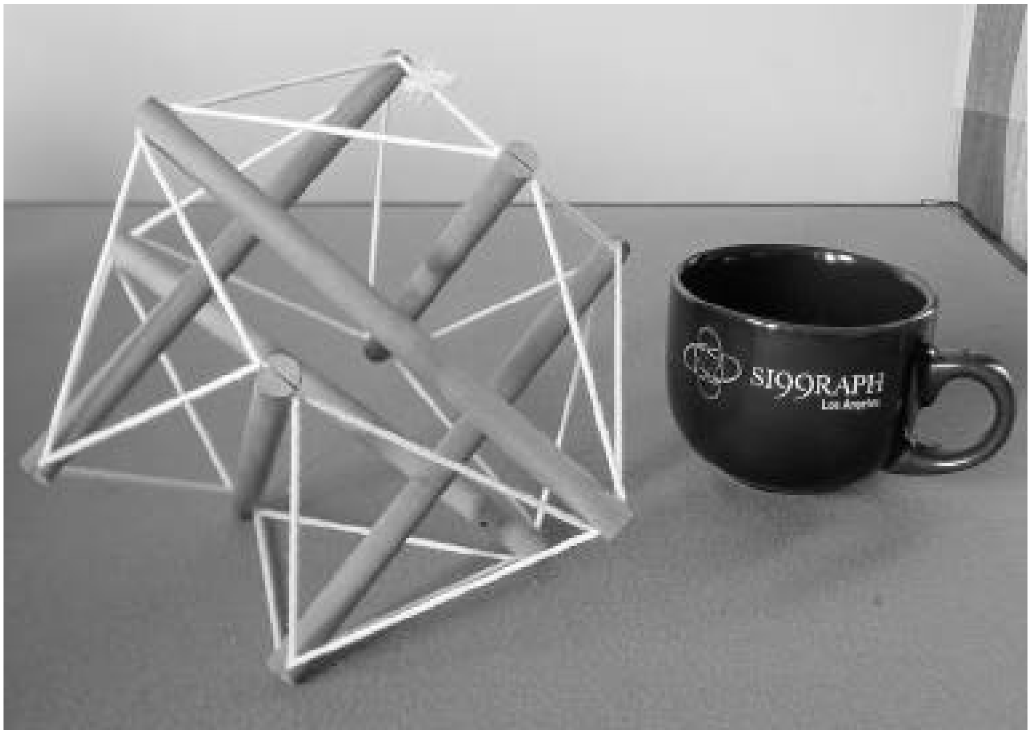


Fig.15

Fig. 16

3.4 Turning a torus inside out

A torus is the shape of a tire or life-belt. It is a tube that runs around a circle. Suppose we have a torus made of some flexible fabric. Make a hole in it and turn it inside out through the hole. What shape do you get?

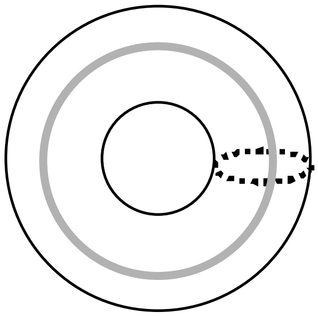


Fig. 17

Someone once told me that turning a torus inside out was impossible. The argument went thus:

“Suppose there is a line painted around the outside surface, (the gray line in Fig. 17) and another painted on the inside (the dotted line of Fig. 17), these lines are unlinked. But when you turn the torus inside out, the dotted line is on the outside and the gray line is on the inside. The unlinked lines become linked. Since this is impossible, you can’t turn the torus inside out.”

Is this right? What happens if I try?

Can you replace the ideal torus with a familiar object to solve this conundrum? Maybe an article of clothing will do it.

Session 4, 3.15 – 5.00

4.1 Road safety

In "Seeing for safety," The Traffic and Road Research Laboratory (UK) report makes clear the contribution that spatial ability has on road deaths. Inefficient spatial perception is responsible for many crashes. Don't accept the notion of *accidents* — crashes are *caused!*

Turning across major road traffic on a dual carriageway

Turning across traffic is the most frequent cause of death on the road. This major cause of crashes appears inexplicable. The correct procedure requires checking the rear-view mirror, signalling, then pulling to the middle of the road, applying handbrake, and selecting neutral, to wait for a gap in oncoming traffic. Occasionally, after carefully carrying out this maneuver the driver then pulls out when no gap exists! An article in *The Guardian* some years ago described this phenomenon precisely. The author had been following a driver for some time, and noting how well he was driving, The driver ahead, eventually pulled out to pass roadworks, and then signalled again to show that he was intending to turn right. After some time he suddenly pulled out in front of an oncoming van. The phenomenon could be explained by the birthday card or spinning cube effect, or perhaps they see the approaching vehicle as being on the far lane and further away. Certainly, it is an optical illusion. After staring at the oncoming traffic a dangerously incorrect view is perceived. A driver pulling out in front of a truck travelling at 30 mph is usually killed, however survivors always accuse the approaching driver of accelerating at them. This would fit with the explanation that the waiting driver originally saw the truck as being further away and travelling slowly.

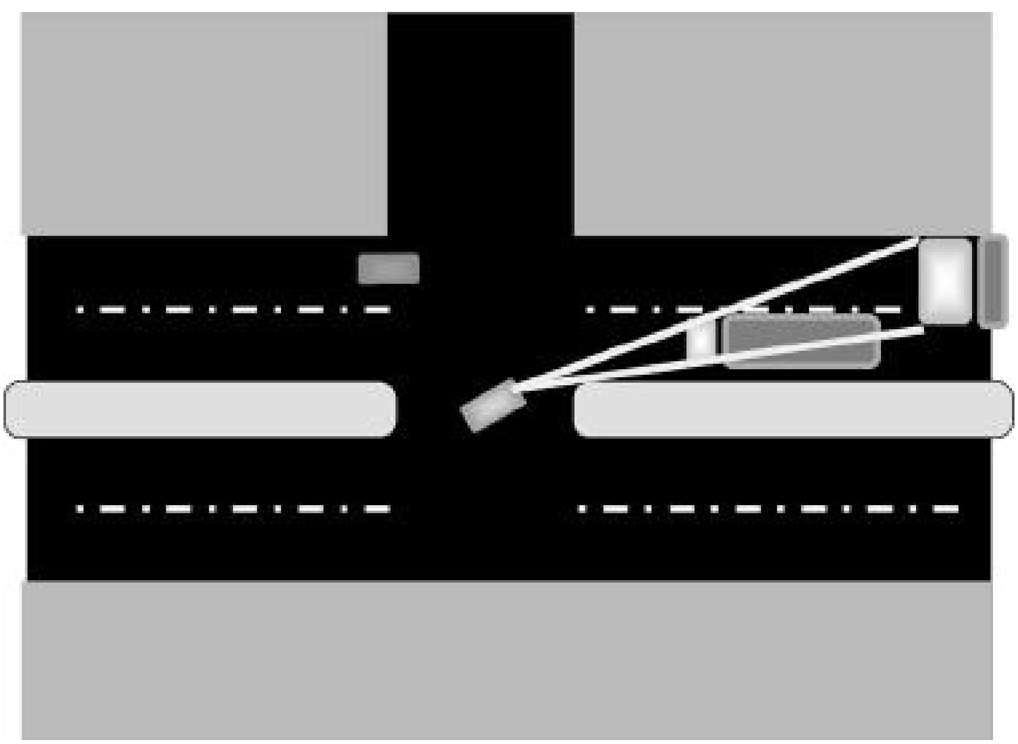


Fig. 18: The truck appears larger and further away in the other lane.

The advice for drivers attempting to turn across traffic is to keep changing their view. When the road appears to be safe, look away down the road that you intend to enter. If, when you look back, the truck is still at a safe distance, then engage gear and go. Drivers on the main road, approaching a driver waiting to turn, should be aware that the waiting driver may pounce at the last moment.

As difficult as this idea may sound, the full story is even more complicated. In *The Inner Game Of Tennis*, the author, W. Timothy Gallwey, talks of a player's 'self 1' and 'self 2'. 'Self 1' interferes with the way 'self 2' is playing the shot. A similar situation exists when driving. It is extremely important to apply the handbrake and engage neutral, when preparing to turn right, otherwise if you sit with the car in first gear, riding the clutch, your 'self 2', sure that it is safe, may release the clutch while 'self 1' is checking the side road.

In an article in *New Scientist* (5 September 1998) Bob Holmes writes:

> What you see "out there" is often illusion, not reality. And to cap it all, you yourself are not fully in charge of your own perceptions and actions.

Motorway mind set

A large number of crashes occur after drivers leave a motorway (highway). Drivers become set into 'motorway mode' and are unable to cope with roundabouts on leaving the motorway. In some countries, yellow lines are drawn across the exit road to change the awareness of the drivers. According to The Traffic and Road Research Laboratory, drivers do not slow down more than they would if the lines were not there, **but they do wake up to the fact that they have left the motorway!**

Collisions on the hard shoulder of motorways

Many vehicles, including brightly coloured AA and RAC vans with flashing yellow roof lights, have been hit whilst repairing a car that had broken down on the hard shoulder of a motorway, sometimes with fatal results.

An experienced motorway driver tends to run on 'automatic pilot' guided by a form of 'expert system rules' based on his experience. Two rules are:

> "All vehicles on the motorway are moving."

and

> "As a good truck driver I belong in the nearside lane."

When a truck driver comes in sight of a car parked on the hard shoulder, his interpretation is of a moving car in the lane further to his left. Unfortunately, he is seeing it at such a distance that it is within 'fovea vision', a very small central area of the retina which has high resolution but poor motion detection. He therefore pulls over to follow in what he believes to be the nearside lane. When he gets close enough for the vehicle to appear outside his fovea vision, he discovers his mistake and attempts to pull out, but too late.

One would think that a blue flashing light would certainly bring a driver out of automatic mode, but the police have been hit in the same circumstances, so another solution has to be found. We have to change the driver's perception of the situation. Truck drivers are aware of this problem, so that when they break down, they stand the seat from their cab against the back of the truck. Following drivers, utilizing the excellent resolution of fovea vision would see the seat and would know that they could not be moving. Car drivers cannot easily remove the car seat, but they can produce a similar effect by parking at a slight angle on the hard shoulder. Following drivers being able to see down the side of the car, would realize that the car would have to be moving sideways if, indeed, it were moving, so they do not pull over to follow. Motoring organizations now park this way. They say that it is so that their van would be knocked off the motorway when hit, rather than into the car they are servicing. You will have noticed that they say 'when', not 'if' they are hit.

Running into the back of stationary vehicles

As explained above, similar situations exist on the highway, as it is difficult to judge the speed of vehicles if they are a long way ahead i.e. in fovea vision. In addition, we become inured to the speed at which we are travelling. There is a story about a motoring correspondent who had been given a ride by a racing driver on a racetrack. As they returned to the pits and slowed, he jumped out at 30 mph! As drivers, we need to remind ourselves constantly to keep a safe distance, at least 2 seconds behind the vehicle in front. The most useful way is to note when the vehicle in front passes a stationary point, e.g. under a bridge. Then to say, slowly, "Only a fool breaks the two second rule". If you always finish the rhyme before you pass the mark, then you are far enough behind in good road conditions. Generally drivers, when they first try this, are surprised at how little of the rhyme they complete.

In the USA they have found that there has been a 54% reduction of rear end shunts in vehicles where a third brake light in the rear window has been fitted. The sudden appearance of a light in an unusual place is certainly effective and being able to see this brake light through the windows of cars ahead is a great advantage. Fit one if it is not already fitted to your car.

Night driving

As explained in Chapter 1, signals falling on the cone receptors of the retina are interpreted faster than signals via the rods. As only the rods are operating in poor light, everything takes longer to interpret. Not only is it more difficult to see anything at night, but it takes longer to work out what is there. Be aware that your vision is impaired at night and drive even more carefully.

4.2 Nova Plexus: understanding structure

Nova Plexus (1978) is a small abstract sculpture by Geoff Wyvill. It consists of twelve turned stainless steel rods that interlock in an interesting way. It is shown in Fig. 20 on page 30, together with a SIGGRAPH mug to indicate the scale.

Also shown are twelve wooden rods and four rubber bands. You are asked to build a copy of the Nova Plexus structure with these materials.

Before you start, study the picture. Then cover it up and answer the following:

1. The structure has twelve rods. How are they arranged?

2. The broad appearance is a kind of 3D star. How many rods meet at each point of the star?

3. How many other rods does each rod touch?

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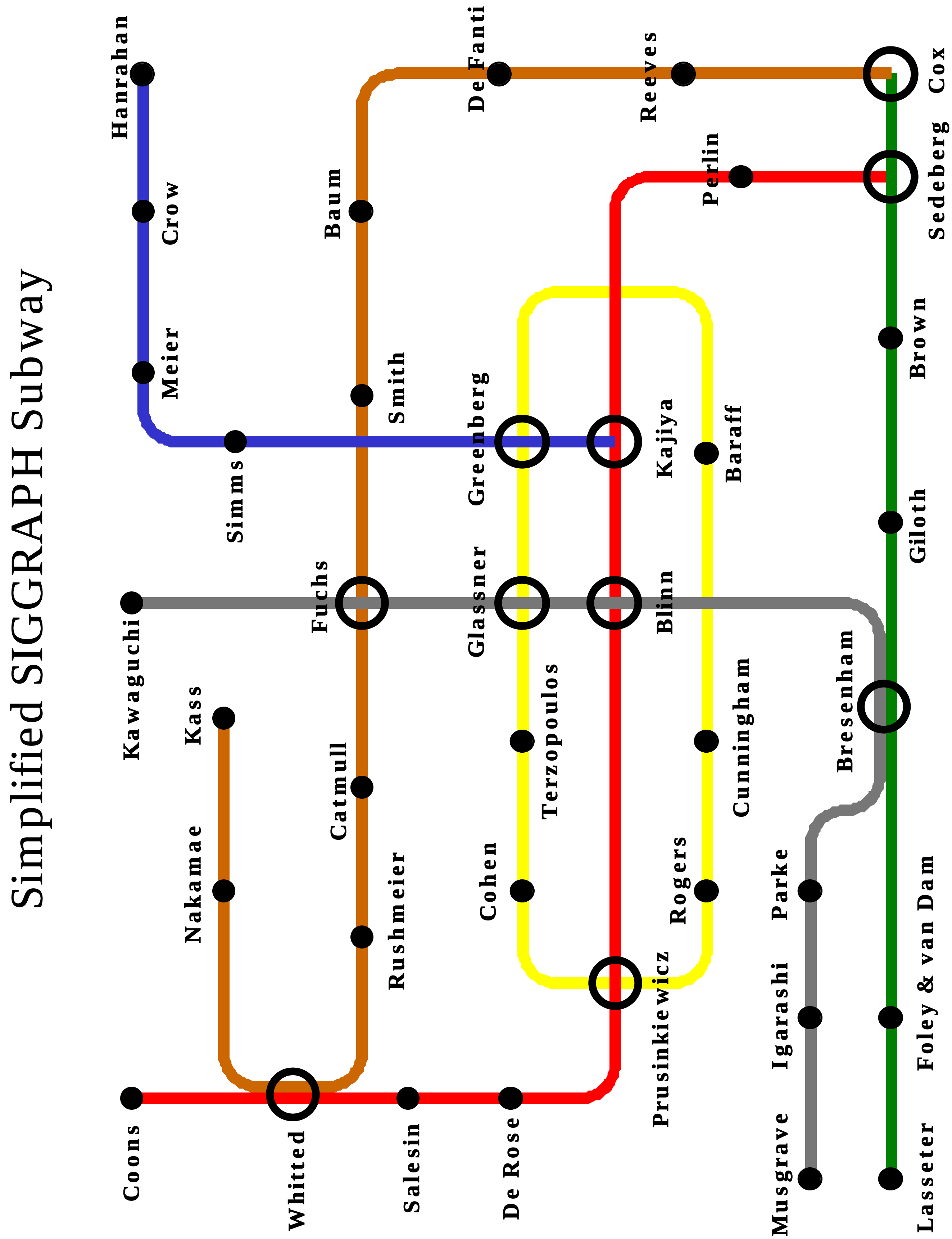

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Giloth
Kawaguchi
Fuchs
Glassner
Blinn
Bresenham
Kass
Catmull
Terzopoulos
Cunningham
Nakamae
Rushmeier
Cohen
Rogers
Parke
Prusinkiewicz
Igarashi
Foley & van Dam
Coons
Whitted
Salesin
De Rose
Musgrave
Lasseter

Fig. 19

Fig. 20: Nova Plexus and materials

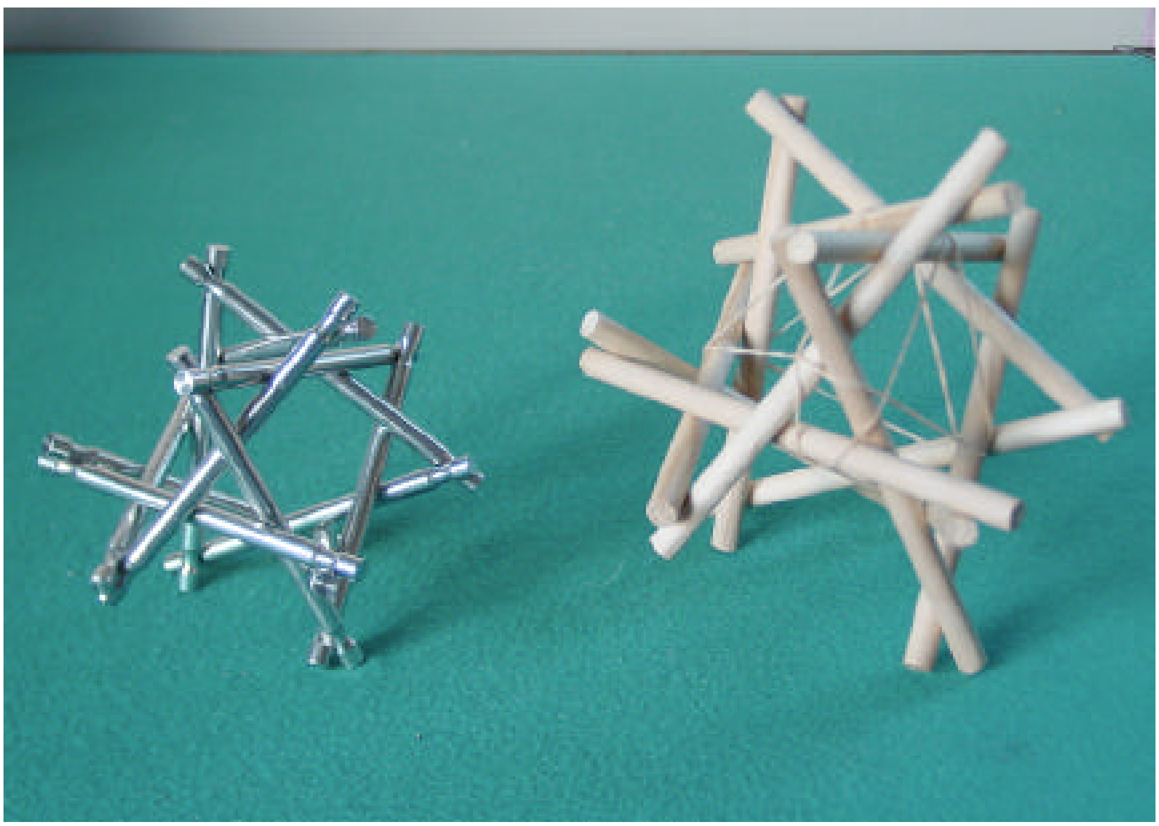


Fig. 21: Wooden Plexus with original for comparison

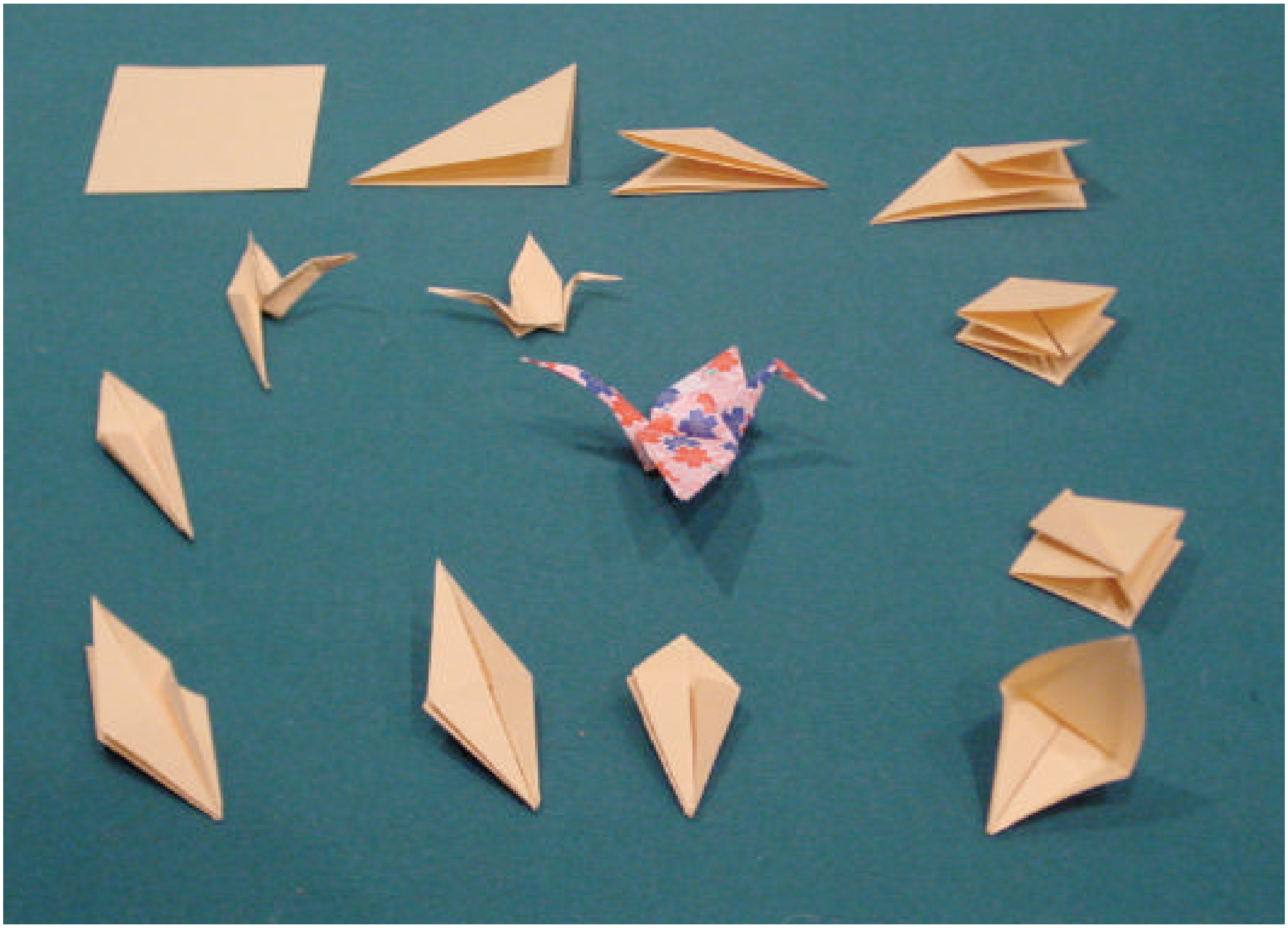
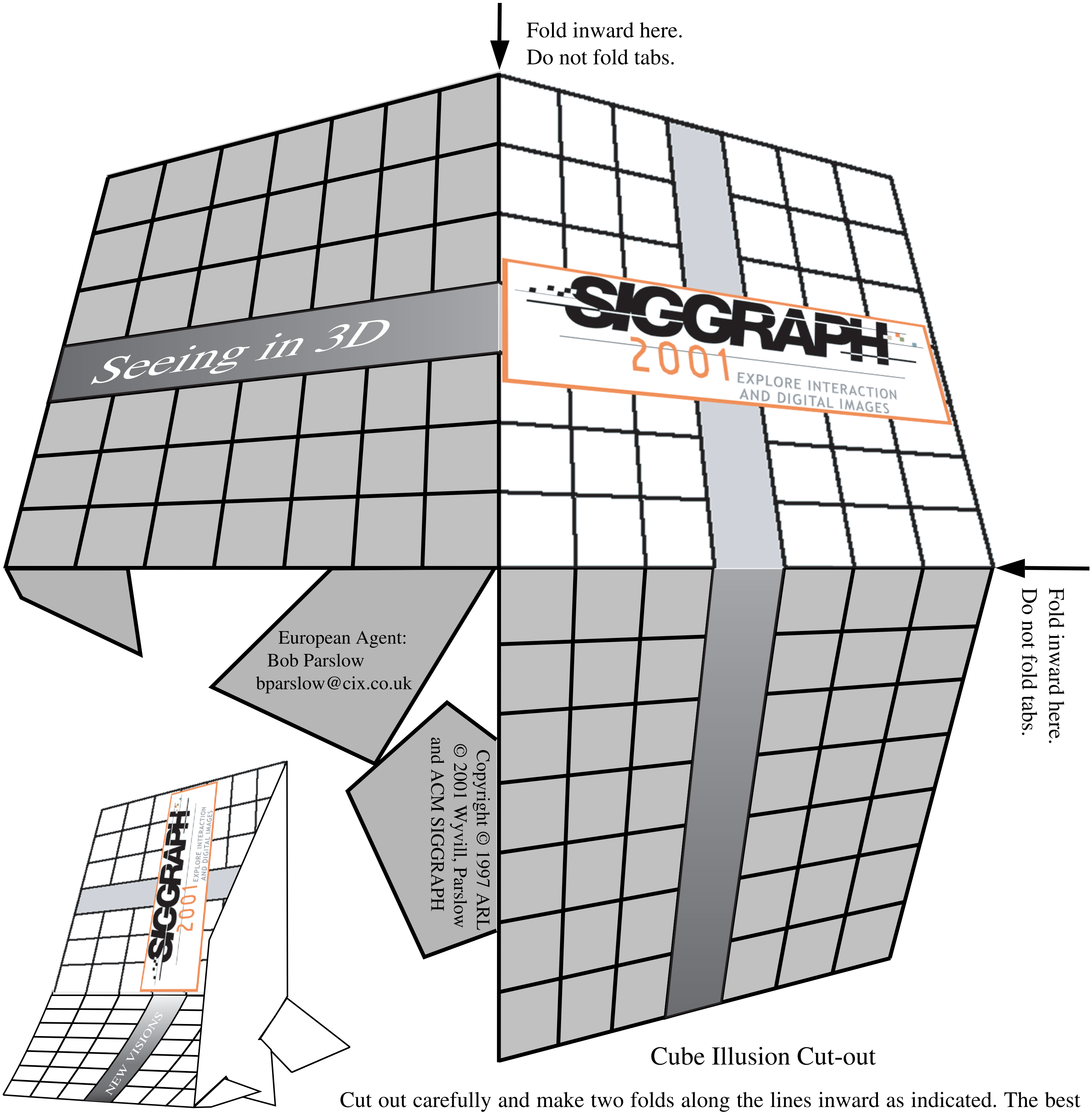


Fig. 22: Stages of folding a paper crane.



Cube Illusion Cut-out

Cut out carefully and make two folds along the lines inward as indicated. The best way to make a straight fold is to score lightly along the line first, or to lay the card on a flat surface and bend up against a ruler's edge.

Fold the model up into a hollow corner of a box as shown, with writing on the inside of the box. Do not fold tabs. Ease the angled tabs together. Stand the model on a table with the tabs down.

View from about six feet away. If you don't see the illusion immediately, try closing one eye. When you can see it easily, move your head slowly. Then try holding the model in one hand at arm's length. When it inverts, crazy things seem to happen as you move it.